

Assimilation of Multi-Sensor Synoptic and Mesoscale Datasets: An Approach Based on Statistic, Dynamic, Physical and Synoptic Considerations

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LONG-TERM GOALS

Our long-term goal is to contribute to our understanding of key elements for improving the 2 to 3-day forecast of Pacific and Atlantic storms that strike the west coasts of the U. S. and Europe through analysis and assimilation of observations. Of particular interest to us are the combined effects of satellite data and in situ data (dropsondes, buoys, ships) on the initialization of a numerical forecast model aimed at providing reliable objective forecast guidance.

OBJECTIVES

To conduct data assimilation experiments using observations available during FASTEX and NORPEX, and a mesoscale forecast model. We focus, specifically, on two technical and one scientific objectives, listed below:

1. the best use of satellite data (TOMS ozone and water vapor winds), targeted dropsondes, and results from subjective mesoscale analysis.
2. the role of targeted observations in the presence of satellite data for improving 2 to 3-day forecasts of landfalling cyclones.
3. the role of the background term in mesoscale data assimilation (scientific goal).

APPROACH

We developed two 4D-Var systems: one uses a large-scale global spectral model (the NCEP medium-range forecast model), and the other uses a mesoscale model (MM5). Technical approaches involve:

1. Four-dimensional variational data assimilation (4D-Var) with the Penn/State NCAR non-hydrostatic mesoscale model version 5 (MM5).
2. Adjoint sensitivity study.
3. Singular vector calculations.
4. Hand synoptic analysis.

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The 4D-Var experiments assess the impact of various types of data, and the adjoint sensitivity and singular vector calculations provide additional insights into the key components for data assimilation and prediction, given the fact that the data are most likely insufficient.

Key individuals:

1. Drs. Zou, Xiao, and Pondeva: 4D-Var, adjoint sensitivity study, singular vector calculations and analysis of numerical results.
2. Graduate students Mrs. Peng and Jang: idealized model and simplified problems.
3. Dr. Shapiro: Synoptic analysis.

WORK COMPLETED

A case study of the impact of vertically integrated ozone data on the forecast of a mid-Pacific cyclone was completed. The model assimilation of the integrated ozone observations from the NASA Total Ozone Mapping Spectrometer (TOMS) was performed via the 4D-Var approach.

A case study of the impact of targeted dropsonde data on a NORPEX oceanic cyclone was conducted using a version of the NCEP 3D-Var system and a newly developed 4D-Var system.

A case study of the impact of satellite-derived water vapor wind vectors (GMS winds) on the prediction of a major NORPEX cyclone over the mid-Pacific Ocean was conducted. This cyclone appeared to have a controlling impact on the success of a 2 to 3-day forecast of a secondary cyclone downstream which made landfall on the west coast of the U.S on 23 February 1998.

A case study of the impact of NORPEX Targeted Dropsondes on the Prediction of a Downstream East-coast Cyclone Development was performed through the combined use of Synoptic Analysis and the 4D-Var Approach.

An ensemble prediction system was developed and tested on four case studies during the NORPEX period.

RESULTS

1. Use of TOMS Ozone Data for the Prediction of a NORPEX mid-Pacific cyclone

A 4D-Var setup was used to assimilate TOMS integrated ozone data into the MM5 mesoscale model. The study concentrated on the forecast of a NORPEX mid-Pacific cyclone between 19 and 24 February 1998. It was first shown that the TOMS ozone data correlated linearly with the integrated Ertel Potential Vorticity (PV) calculated from the 12-hourly available NCEP analysis. Two different strategies were used to assimilate the ozone observations: In the first strategy, the latitude dependent regression coefficients were used to formulate the model operator for the integrated ozone. The second strategy consisted of assimilating a three-dimensional "observational" PV field derived from the TOMS ozone. The PV field was obtained through a simple empirical iteration procedure that used the integrated TOMS ozone to correct the initial PV field of the analysis initial condition.

The 2 to 5-day control forecast that did not benefit from ozone assimilation misplaced the cyclone center and underestimated its intensity. The ozone assimilation lead to small, but significant improvements in the cyclone forecast. In particular, it lead to a more pronounced deepening of the sea level central pressure and upper level PV poleward cyclonic wrap-up. Targeted dropsonde wind and temperature observations from NORPEX were used for verification, and confirmed the positive impact of the ozone data on the model forecast.

Further improvements in the forecast skill were obtained through the use of energy metric singular vector based ensemble forecastings. In particular, it was shown that ensemble members computed on reference trajectories that benefited from the assimilation of the TOMS ozone lead to a better forecast skill than those based on the control trajectory.

2. The Impact of NORPEX Targeted Dropsondes on a Land-Falling Pacific Winter Storm Forecast Using NCEP 3D-Var and 4D-Var Systems.

A manuscript entitled ``The Impact of NORPEX Targeted Dropsondes on the 2-3 day Forecasts of a Landfalling Pacific Winter Storm Using NCEP 3D-Var and 4D-Var Systems" has been submitted to the Monthly Weather Review, and is currently in the review process.

The paper deals with the assimilation of dropsonde data collected north of Hawaii during 29-30 January 1998, near a low center that later struck the U.S west coast. Assimilation of these data using both the 3D-Var and 4D-Var approaches led to improved 48-h forecasts over the northeastern Pacific Ocean, where the control forecast produced large errors. The results indicated the (original) NORPEX forecast verification region was not an adequate choice for the assessment of the dropsondes maximum impact for this particular case. Both the NOGAPS and NCEP operational systems found a negative impact of these targeted dropsondes on the 48-h forecast of wind and surface pressure fields over the NORPEX forecast verification region (see Langland, et al., 1999, Bull. Amer. Meteor. Vol 80, pgs.1363-1384).

3. A Case Study of a NORPEX Oceanic Cyclone: Impact of Satellite-Derived Wind Vectors.

A manuscript entitled ``Impact of GMS-5 and GOES-9 satellite-derived winds on the prediction of a NORPEX extratropical cyclone " has been submitted for publication in the Monthly Weather Review. The paper focuses on the period 1200 UTC 19 February to 1200 UTC 21 February 1998, characterized by the development of a strong cyclone in the mid-Pacific. This cyclone had an impact on a later cyclone which developed downstream and made landfall over the west-Coast of the United States on 23-24 February. The control forecast initiated from the NCEP analysis enhanced with an objective analysis of radiosonde, surface and ship observations underestimated the deepening of the mid-Pacific cyclone and yielded rather unsatisfactory wind shears and temperature gradients. Incorporation of satellite wind observations was found to increase the cyclonic zonal wind shear and the cross-front temperature gradient associated with the simulated cyclone. Sensitivity studies revealed the cyclone was more sensitive to the lower rather than the upper atmosphere. The best forecast of the cyclone was obtained with the use of 4D-Var analysis assimilating satellite-derived winds, increased model resolution, and advanced model physics.

4. The Impact of NORPEX Targeted Dropsondes on the Prediction of a Downstream East-coast Cyclone Development through the combined use of Synoptic Analysis and the 4D-Var Approach.

The NORPEX targeted dropsonde data deployed at 00 UTC 20 February 1998 north of Hawaii in a frontal region affected the 1-2 day forecast of a mature cyclone near the U. S. west coast, and the 2.5-5 day forecast of a developing cyclone along the U. S. south east coast. Assimilation of a set of manual analysis, prepared by Mel Shapiro based on these targeted dropsonde observations, doubled the positive data impact on the intensity forecast of the south east coast cyclone. This study indicated the need to include some sort of flow structure in mesoscale data assimilation. Studies are being conducted to develop automated methods for including regime-dependent structures in the mesoscale data assimilation for different weather regimes such as cyclone, dryline, winter blizzard, hurricane etc. The approaches include a modification of the circular Cressman-type regions of influence to account for mass and wind gradients in the background flow, as well as the use of singular vectors of a mesoscale model to approximate the background error covariance matrix.

A paper entitled "Assimilation of a set of manual synoptic analysis derived from NORPEX targeted dropsonde data: Implication of the use of a weather-dependent structure function to mesoscale data assimilation" is being completed.

5. Ensemble Prediction System with the use of singular vectors.

A manuscript entitled "The Impact of singular vector based ensemble forecastings with a mesoscale model on the prediction of NORPEX extratropical cyclones" was submitted to the special NPG journal issue. This work is a follow-up to our adjoint sensitivity experiments on model cyclones for the NORPEX period. A proxy to the energy metric singular vectors of the linearized MM5 were used as ensemble members. Four case studies were performed covering the period from 1200 UTC 4 February to 1200 UTC 24 February 1998. All case studies showed promising results: measured in terms of the mean-squared error and correlation coefficients, the mean ensemble forecasts were always more skillful than the control forecasts. The range of forecast results obtained from the ensemble members seemed to also quantify well the uncertainty of any one single forecast. In one case study, dropsonde data from a location next to a mature mid-Pacific cyclone were used for verification. Compared with the control forecast, the mean ensemble forecast was found to yield slightly improved vertical profiles of wind and temperature, especially between 850 and 400 hPa. It was concluded that an ensemble prediction system with a limited area mesoscale model could realistically improve the prediction of Pacific cyclones that impact the west coast of the U.S. Further work will be necessary to refine the ensemble system. This includes sensitivity studies to the initial perturbation amplitudes, model resolution and physics. It also seems necessary to develop verification criteria more appropriate to the mesoscale.

IMPACT/APPLICATIONS

The results obtained from the assimilation of TOMS ozone data confirm our earlier assessment that this data type can play an important role in future experiments such as THORPE. They complement other satellite data such as radiances which depend on the thermodynamic state of the atmosphere.

The dropsondes impact study indicates the dependence of data impact assessment on data assimilation approaches and on the selection of targeting and/or forecast verification regions.

The assimilation of satellite-derived water vapor wind vectors may not provide sufficient improvement to the control forecast which fails to predict oceanic cyclone developments in the mid-Pacific. This may result from several reasons: (i) inadequate data quality control, (ii) insufficient data coverage,

especially in the lower troposphere, (iii) model errors in the assimilation model, and (iv) lack of observational information on other state variables such as temperature and moisture.

The combined use of data assimilation and an ensemble prediction system with a mesoscale model seems to be an avenue to be pursued as a means of improving the short-range forecasting of Pacific cyclones that impact the U.S. west coast.

TRANSITIONS

Our MM5 adjoint modeling system is in public domain.

RELATED PROJECTS

``Impact of radar, satellite and targeted *in situ* data on the hurricane forecasts near landfall", funded by NSF-USWRP under the project number ATM-9908939.

``Four-dimensional variational data assimilation and GPS data impact study using NCEP global model", funded by NSF under the project number ATM-9812729.